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All-Optical Frequency Up-conversion using a Semiconductor Optical Amplifier

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Abstract – We present a new scheme of up-converting optical IF signals with an optical LO signal by using SOA. It is able to provide high conversion efficiency and is independent of the incident light wavelengths and polarizations.

I. Introduction

The fiber-optic transmission of radio signals has attracted much attention for broadband radio access system applications because it can simplify base station configuration [1-5]. For the increase of the total data traffic capacity, wavelength division multiplexing (WDM) technique can be introduced to the radio-on-fiber systems. Millimeter-wave-over-fiber distribution schemes have been demonstrated, in which WDM data signals having different wavelengths were up-converted to the millimeter-wave frequency using one Mach-Zehnder modulator (MZM) [1-2]. However, frequency up-conversion using MZM has several problems. Its modulation characteristics depend on the incident wavelength and polarization, and it has a significant amount of insertion loss. In addition, the MZM modulation bandwidth can impose a limitation on the accessible frequency ranges for up-conversion. The technique of optoelectronic mixing has been demonstrated. Photo-detected intermediate frequency (IF) data signals at the base station were mixed with the electric local oscillator (LO) signals by utilizing nonlinearity in three terminal devices such as HEMTs [3] and HBTs [4]. These methods, however, require high frequency electrical LO signal sources at base stations, which will increase the design complexities of base stations. In order to avoid these limitations, an all-optical approach has been tried, where optical IF and optical LO signals having different wavelengths can be utilized. In [5], IF frequency up-conversion to the millimeter-wave frequency was realized by taking advantage of the nonlinear photo-detection behavior of a high-speed photo-detector (PD). This frequency up-conversion scheme, however, has low conversion efficiency.

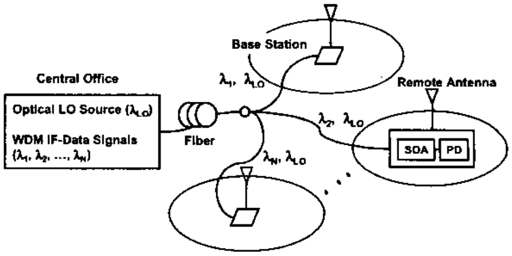

Fig. 1. Radio-on-fiber system configuration for WDM IF signals sharing one optical LO signal

This paper deals with a new all-optical frequency up-conversion scheme using a semiconductor optical amplifier (SOA). The radio-on-fiber system configuration that we have in mind is shown in Fig. 1, where one optical LO signal is distributed to several base stations and IF signals are wavelength-selectively transmitted to base stations. The optical LO signal has two optical sidebands separated by the desired LO frequency (f_{LO}) and is shared among base stations. All optical conversion of the IF signal (f_{IF}) to lower sideband (LSB, f_{LO} - f_{IF}) and upper sideband (USB, f_{LO} +f_{IF}) is achieved in combination with the SOA cross-gain modulation and square-law photo-detection as described in Fig. 2.

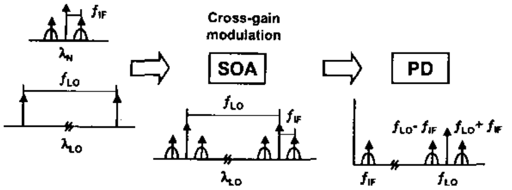

Fig. 2. All-optical frequency up-conversion using cross-gain modulation of SOA and square-law photo-detection of PD

The mixing of two RF-modulated optical signals in SOA has been demonstrated [6]. In this case, however, the RF modulation of both optical signals was limited within the SOA gain modulation bandwidth. In this paper, it is demonstrated that such limitation is not necessary for both optical LO and IF signals. If only one of them (in our case, optical IF signal frequency) is within the SOA gain modulation bandwidth, successful up-conversion is possible. Using this, optical LO frequency much higher than the SOA gain modulation bandwidth can be utilized, which is quite useful for radio-on-fiber applications. In addition, our scheme does not have wavelength- or polarization-dependence, and frequency up-conversion is possible for a wide range of separation between IF and LO wavelengths as long as both are within the range of SOA optical gain.

II. Experiments and Results

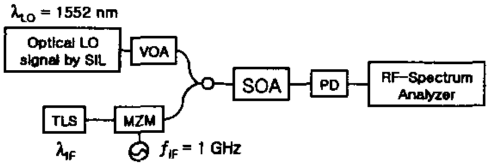

Fig. 3. Experimental setup for all-optical frequency up-conversion using SOA. TLS: tunable light source, VOA: variable optical attenuator, MZM: Mach-Zehnder modulator.

Fig. 3 shows the experimental setup used for demonstrating all-optical frequency up-conversion with an SOA. Optical LO signal is generated by the sideband injection locking (SIL) technique [7], and has two optical sidebands separated by the desired LO frequency (f_{LO}) as illustrated in Fig. 2. In SIL, three separate DFB lasers are used. One DFB laser, acting as master laser, is RF-modulated and produces the multiple sidebands. Two of the sidebands having the target LO frequency separation are used to injection-lock two separate DFB lasers acting as slave lasers. When the output lights from two injection-locked lasers beat each other in PD, the target LO signal with low phase-noise can be achieved. The optical LO power level is adjusted with a variable optical attenuator (VOA) for the SOA input.

The optical IF signal is produced by the intensity modulation of a Mach-Zehnder modulator at 1 GHz. A tunable laser source (Anritsu MG9628A) is employed for the IF optical signal wavelength to be tuned over 80 nm (1500 nm ~ 1580 nm). The IF optical power is set at −10 dBm for SOA input. For simplicity, no data modulation is employed in the experiment.

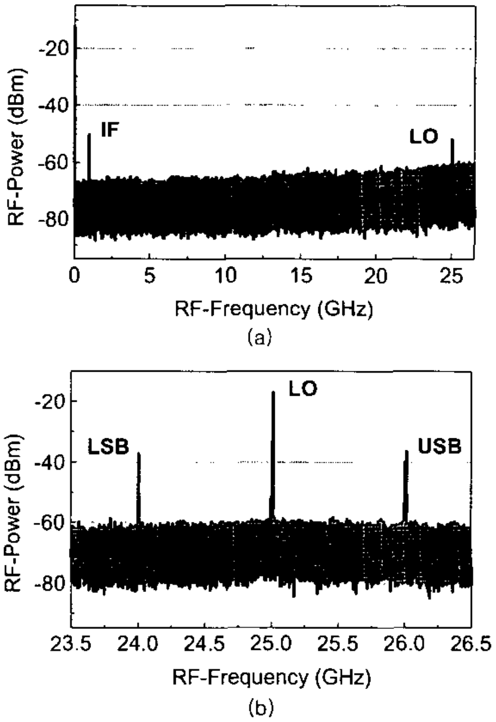

Fig. 4. Measured RF-spectra before (a) and after (b) SOA, when biased at 150 mA and, λ_{IF} = 1540 nm and λ_{LO} = 1552 nm.

Optical IF and LO signals co-propagate

through SOA. The SOA (Samsung OA40B3A) used in the experiment has less than 1 dB polarization dependence loss and has, when biased at 150 mA, larger than 40 nm of 3 dB optical bandwidth, larger than 7 dBm in output saturation power. No polarization control is used. An optical attenuator is placed before PD in order to avoid any non-linear photo-detection at the large optical power [5], which may interfere with up-conversion process.

Fig. 4(a) and (b) are the RF-spectra of IF and LO signals measured before and after SOA. One can observe clearly that, after optical IF and LO signals co-propagate through SOA, the IF signal at 1 GHz is up-converted to LSB (24 GHz) and USB (26 GHz). In addition, these LSB and USB signals (Fig. 4(b)) have larger RF powers by over 10 dB compared to IF signal power before SOA (Fig. 4(a)). This implies that SOA provides gain to the up-conversion process. With this, the conversion efficiency is much larger than in schemes using external optical modulators [2] or high speed PDs [5]. Although the amplified spontaneous emission in SOA enhances the overall noise level, it is experimentally found that the phase-noise degradation of the LO signal is negligible.

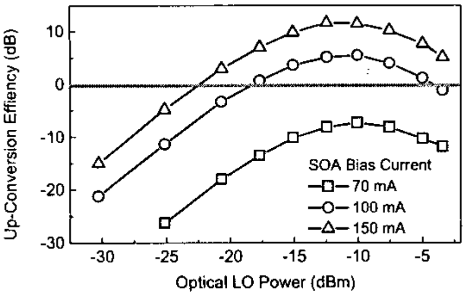

Fig. 5. Up-conversion efficiency with optical LO power when λ_{IF} = 1540 nm and λ_{LO} = 1552 nm.

In order to investigate the dependence of conversion efficiency, the up-converted USB RF-powers are measured as function of various SOA bias currents and optical LO powers for one fixed optical IF power (−10 dBm). The results are shown in Fig. 5. The conversion efficiency is defined as the ratio of the up-converted USB RF-power to the IF RF-power, measured from the photo-detected currents with and without SOA, respectively. Fig. 5 shows that the up-conversion efficiency increases with SOA bias current levels indicating that the conversion efficiency is directly attributed by the optical gain in SOA. Fig. 5 also shows that, for the given SOA bias current, the efficiency initially increases with the LO optical power but decreases after a certain LO optical power level. This is due to the SOA optical gain saturation. The optical gains provided by SOA are almost constant for the low optical inputs, but decrease for the relatively high optical power inputs. In this present case, it has the optical LO power tolerance of about 15 dB for the positive conversion efficiency, when biased at 100 mA and the IF optical power is of −10 dBm.

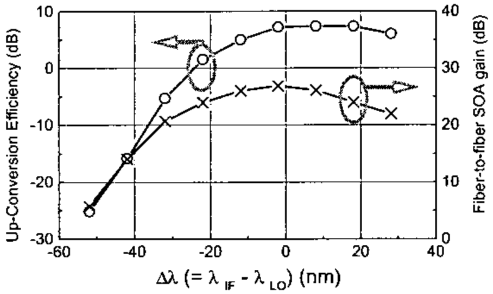

Fig. 6. Up-conversion efficiency with optical LO power, when SOA is biased at 100 mA and λ_{LO} = 1552 nm. λ_{IF} is wavelength-tuned off from λ_{LO}.

Fig. 6 shows the dependence of the frequency up-conversion efficiency on the SOA input wavelengths. In this case, the optical LO signal wavelength is fixed at 1552 nm, and the optical IF signal is wavelength-tuned from 1500 nm to 1580 nm. The optical IF and LO signal powers are −10 dBm and −11 dBm, respectively. The origin of the horizontal axis indicates the optical LO wavelength. Fig. 6 also shows the fiber-to-fiber SOA gain for the given SOA bias current level. At the shorter wavelength, the SOA is not able to obtain optical gain enough to achieve the positive efficiency. When the IF wavelength is close to the optical gain peak, however, the positive efficiency can be achieved. Under the conditions of Fig. 6, the positive efficiency can be achieved at the wavelength-range of more than 50 nm. Therefore, the wide wavelength separation between λ_{LO} and λ_{IF} is possible for the frequency up-conversion.

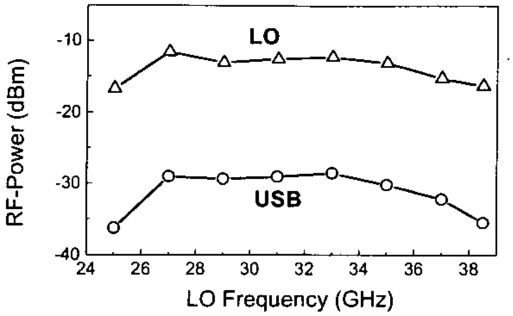

Fig. 7. Up-conversion for several LO frequency when f_{IF} = 1GHz, λ_{IF} = 1540 nm and λ_{LO} = 1552 nm.

Fig. 7 shows the dependence of the post-converted LO and USB RF-powers for the different LO frequencies. The frequencies of the optical LO signals are synthesized by the sideband injection locking method. Because a high-speed PIN PD (Discovery, DSC10ER, 3dB BW = 50 GHz) and LNA (Miteq, JS3, 26~40 GHz) are employed for the measurements above 26 GHz, the direct comparison in the up-conversion efficiency is not made. Instead, the measured RF-powers of LO (25 GHz) and USB (26 GHz) signals of Fig. 4(b) are given as reference in the figure.

Fig. 7 shows clearly that the frequency up-conversion process is possible for LO signal frequencies even when the LO signal frequency is much higher than the SOA gain modulation bandwidth. Therefore, up-conversion is possible for the wide range of IF frequencies as long as they are within the SOA gain modulation bandwidth.

III. Conclusion

We presented a new all-optical frequency up-conversion scheme using cross-gain modulation effect in SOA. Specifically, we demonstrated that all-optical frequency up-conversion is possible for the LO frequency that is much larger than SOA modulation frequency, and with positive conversion efficiency. In addition, the optical LO and IF signals can have a wide wavelength separation. These features are very useful for radio-on-fiber transmission system applications in which one remote optical LO signal is provided for several WDM IF (or, baseband) signals at different wavelengths.

IV. References

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